

# Horizontal variability of water and its relationship to cloud fraction near the tropical tropopause

Using aircraft observations of water vapor to improve the representation of grid-scale cloud formation in GEOS-5

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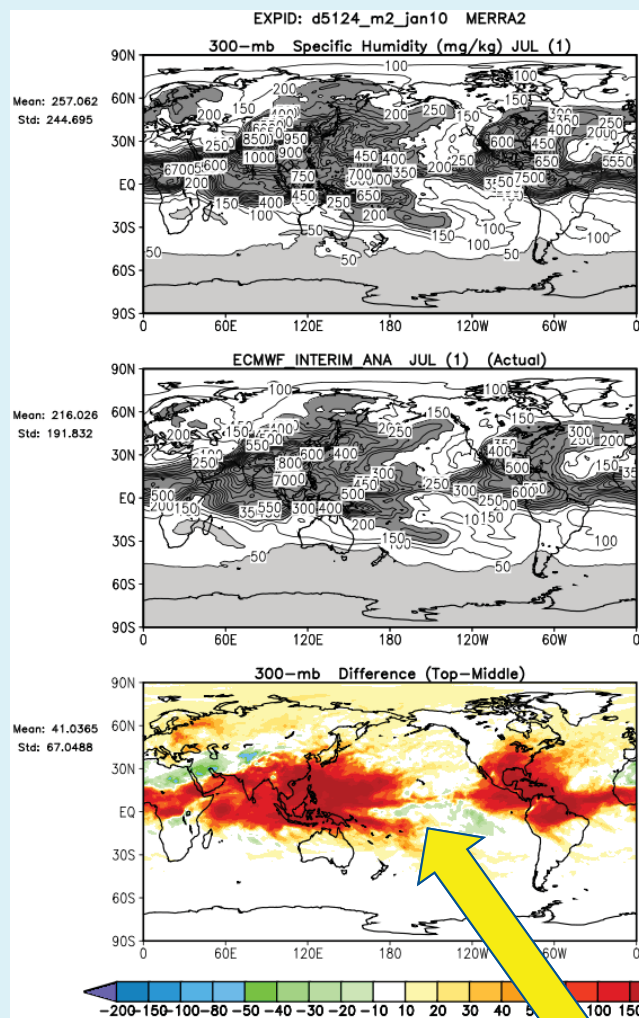
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with data from the DLH, Harvard and JPL groups

# Talk topics

- The chronic water vapor problem in the GEOS-5
- Two possible source and a potential remedy for one
- Motivating science questions
- Overview of cloud processes in GEOS-5
- Methodology: estimating  $RH_{crit}$  from aircraft data
- Initial results from TC4: DC-8 and WB-57
- Summary, long-term goals and future work

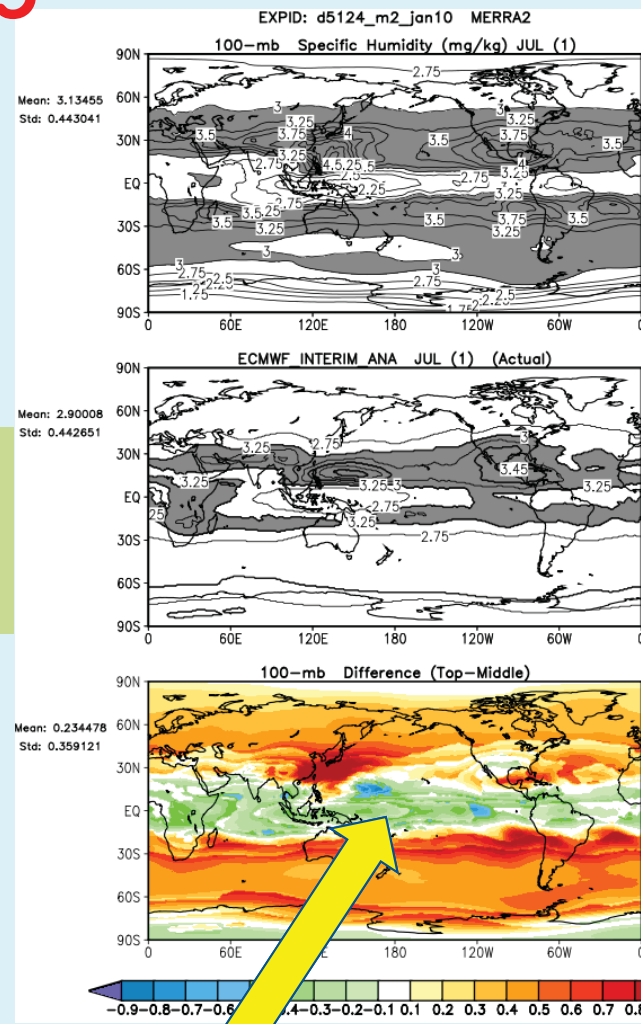
# The chronic water vapor problem in the GEOS-5



GEOS-5

ERA-Interim

Difference



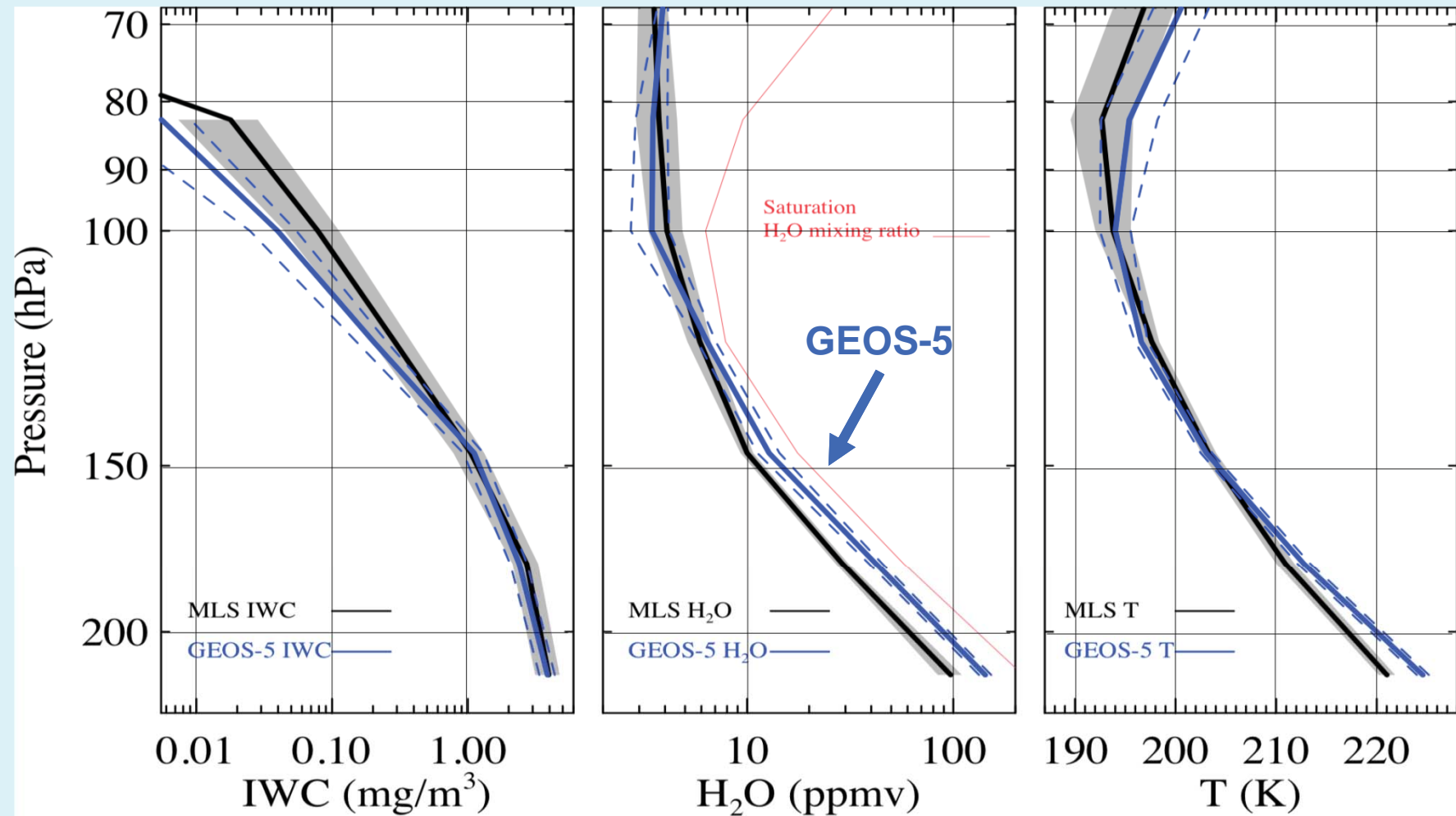
GEOS-5

ERA-Interim

Difference

*GEOS-5 tropics are too wet at 300 hPa but too dry at 100 hPa*

# GEOS-5 vs. MLS



# Two possible causes of the problem:

- *Convective scheme not lofting condensate high enough*
  - ✓ Evidence from ice water
  - ✓ Evidence from CO
  - ✓ Suggestions from TOA radiative balance (OLR, SW)
  - ✓ *At high-res (7 km) with RAS turned way down, problem goes away!*
- *Vertical distribution of condensation processes not properly captured*
  - ✓ Currently extrapolating AIRS results into UT where AIRS provides little information
  - ✓ Need more observations in upper troposphere

# Motivating Science Questions

- What physical processes control the water budget in the upper troposphere and lower stratosphere?
- What is the relationship between thin, cold clouds and supersaturation?
- Given depletion of vapor by numerous small ice particles, are there really extended regions of supersaturation?
- What are the causes of the fine structure of water vapor and what are the implications for cloud formation?
- How will each of these respond to a warming atmosphere?

# Large-scale cloud processes and sub-grid scales in GEOS-5

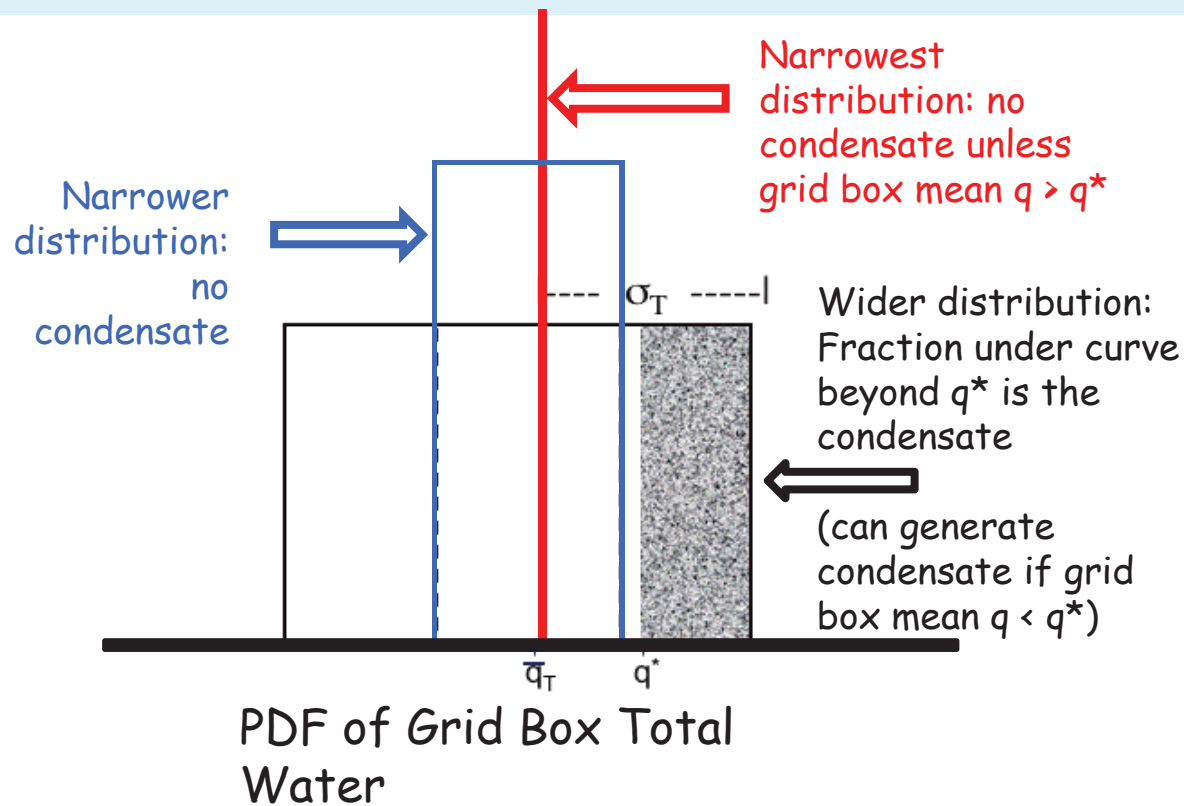
- Like many AGCMs, in GEOS-5 a simple, two-parameter “Top-hat” PDF distribution relates grid-scale  $q$  and cloud fraction to subgrid-scale variations of  $q$
- Vertical variation of top hat PDF width obtained with information from AIRS
- But AIRS provides no real information above 300 hPa, so current PDF falls back to a simple extrapolation

# The PDF formalism

- $q_T$  - total specific humidity
  - $q^*(T)$  - grid-box mean saturation specific humidity
  - $P(q_T)$  - the distribution of  $q_T$  within the grid box
  - Cloud fraction ( $C_f$ )
    - the portion of a model grid box where  $q_T > q^*(T)$
    - formally expressed as integral of  $P(q)$  from  $q^*$  to infinity
  - PDFs such as the "Top Hat" are simplification of  $P(q_T)$ 
    - Width of PDF is standard deviation of  $q_T$  or  $\sigma_T$
    - Define  $RH_{crit} = 1 - \sigma_T / q^*(T)$
- =>  $RH_{crit}$  is the threshold for condensation in a grid box expressed in terms of the grid-scale quantities, i.e. condensation if  $RH > RH_{crit}$



# "Top-hat" PDF parameterization



$$RH_{crit} = 1 - \sigma_T / q^*(T)$$

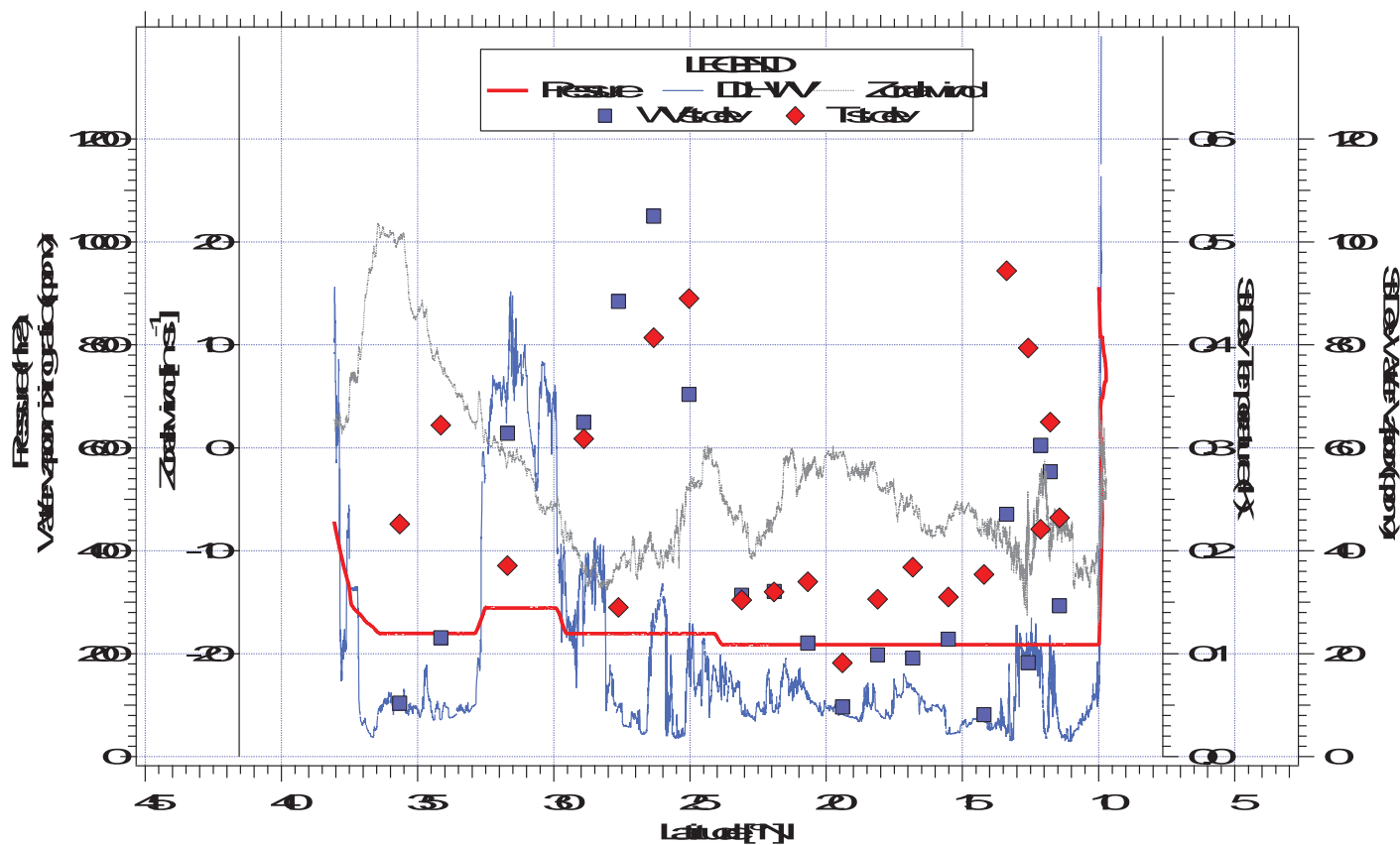
Other distributions in the literature,  
but derived parameters from CRM:

- Triangular - need 3 parameters (assymetry)
- Beta - need 4 parameters

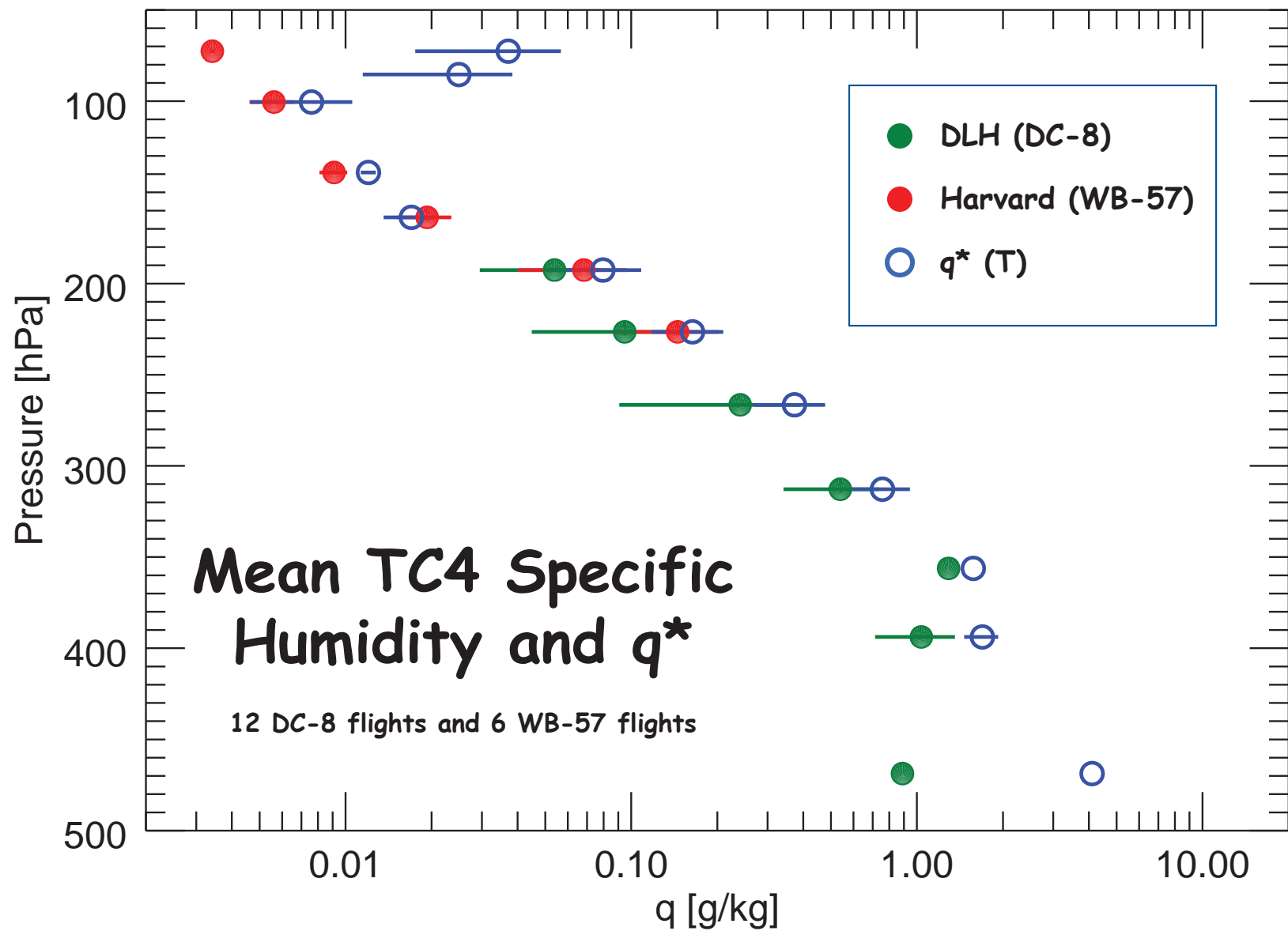
# Estimating $RH_{crit}$ with aircraft observations

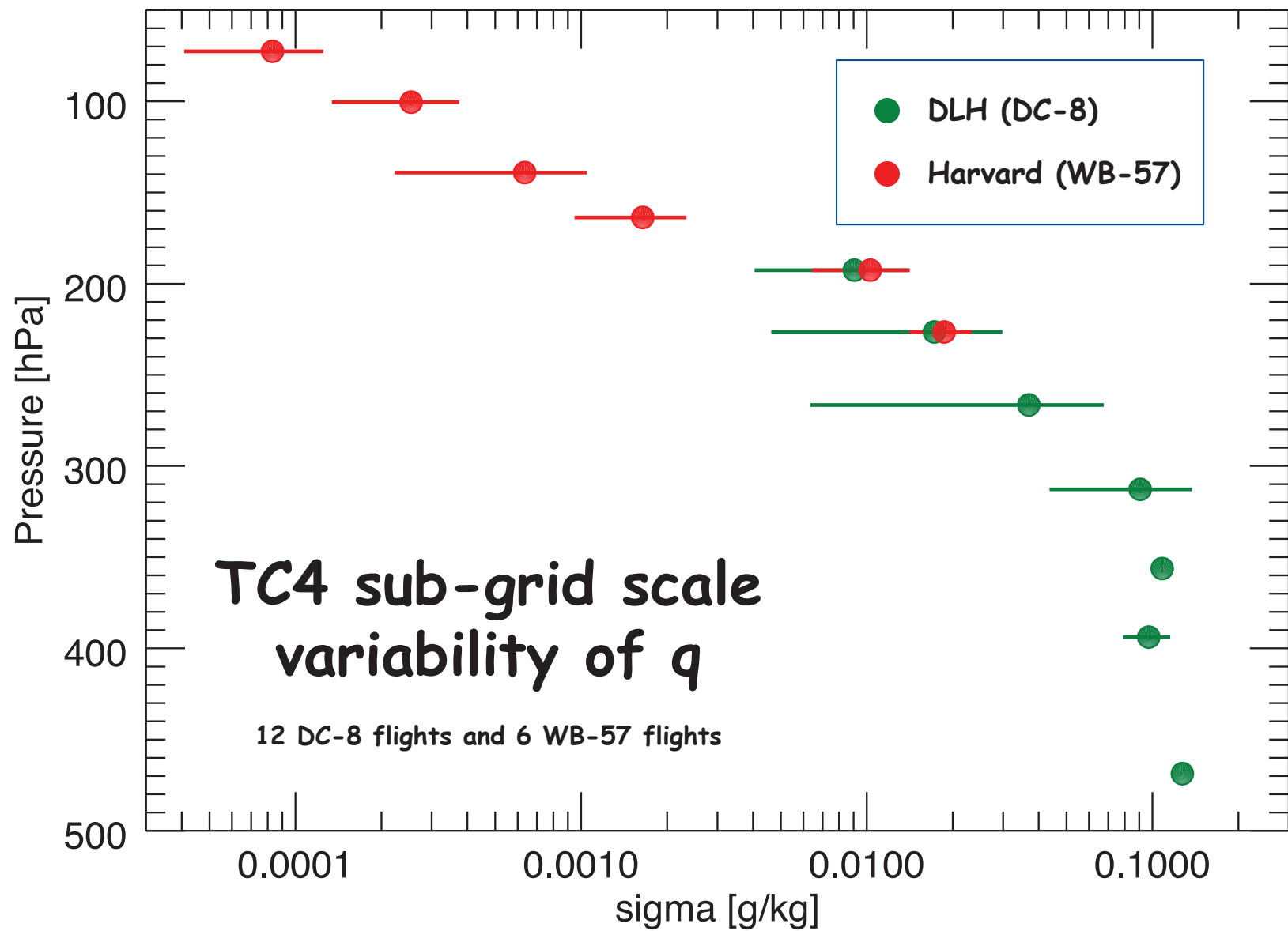
1. Break aircraft flights into level-leg segments equal to model resolution (e.g. 100 km for  $1^\circ \times 1^\circ$  )
2. Estimate sub-grid scale variability in segment with sigma, the standard deviation of specific humidity  $q$
3. Estimate large-scale saturation specific humidity  $q^*$  in segment
4. Derive  $RH_{crit} = 1 - \text{sigma}/q^*$

# Example of DC-8 transit, Dryden to Costa Rica

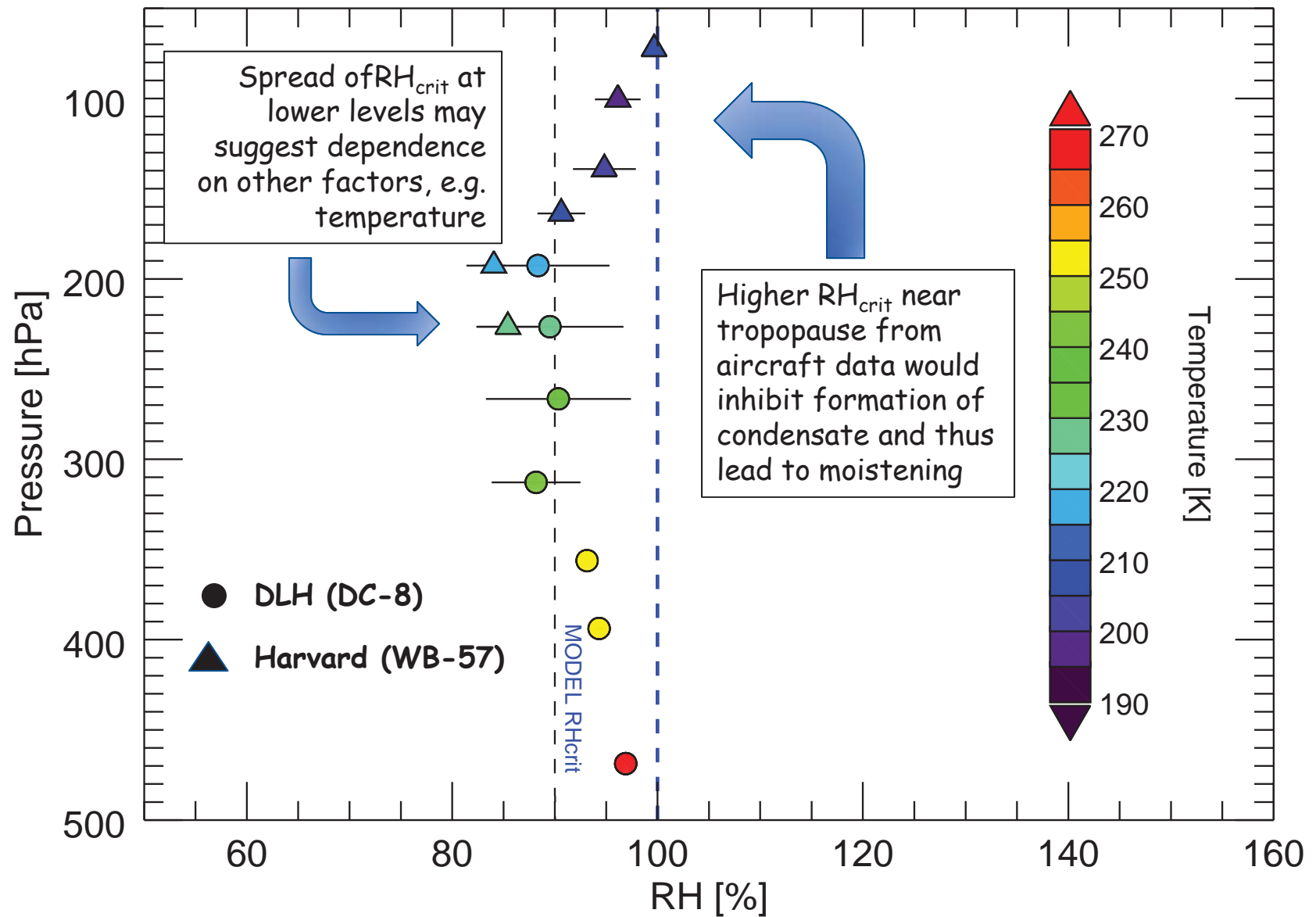


DLH WV mixing ratio and standard deviation (ST DEV) of water vapor and temperature for 200-km on the DC-8 transit, NASA Dryden to Costa Rica, 13 July, 2007. Also plotted are flight-leg pressure and the zonal wind.





# $RH_{crit}$ estimates from TC4



# Summary

- GEOS-5 has a chronic problem of excess moisture at 300 hPa and above in tropics but too little at trop
- Improvement may come by informing PDF parameterization of condensation through estimates of  $RH_{crit}$  profile with aircraft water vapor measurements
- Have done this for a single tropical airborne mission (TC4)
- Encouraging results:
  - Higher  $RH_{crit}$  than AIRS-based estimate near the tropopause (above 200 hPa) should lead to moistening
  - Below 200 hPa seeing spread of estimates, suggesting different large-scale condensation regimes

# Long-term goals

- Reduction of tropical UT wet bias of GEOS-5
- Improved TOA radiative balance
- Improve moisture at tropical tropopause
- With new microphysical scheme, achieve better understanding of water vapor budget & microphysical processes in tropical UT/LS
- Improved model fields for better interpretation of airborne measurements



# Carrying on...

- ATTREX/CONTRAST/CAST provide an extraordinarily rich database of water vapor measurements, particularly in the “gap” between the DC-8 and high-altitude platforms
- Other missions, other environments & seasons: CR-AVE, MACPEX, SEAC4RS, HIPPO
- Analysis of remote sensing data for sub-grid variability
  - CPL data
  - CALIPSO overpasses of opportunity
- Develop state-dependent PDF parameterization for large-scale models (probably not a simple top-hat)